in order to even out the mechanical stress among them. This self assembly process leads to nanopores with uniform pore diameter and arranged in a two-dimensional hexagonally close packed array. This self-assembly process in AAO formation is a slow process and takes hours to reach equilibrium. A commonly accepted procedure to prepare well ordered AAO membranes is called two-step anodization. The concept of the two-step anodization is to first generate aligned nanopores, followed by removal of the initial surface alumina layer. This process generates highly ordered indents on the unreacted aluminum surface. These surface indents serve as the nucleation sites and lead to deep nanopores during the second anodization. Typical Al surfaces with ordered indents are shown in FIG. **2** with indent (pore) diameters around 50 nm and pore-to-pore distance ~110 nm (prepared from 40 V and 0.3 M oxalic acid).

[0011] Typical anodization working ranges and the resulting pore-to-pore distances are, respectively, 10-25 V and 35-70 nm for sulfuric acid, and 30-60 V and 80-150 nm for oxalic acid. These conditions are considered "mild anodization" and the AAO growth rate is relatively slow. Recently, the working ranges for oxalic acid has been extended to 120-150 V with the corresponding pore-to-pore distance expanded to 220-300 nm under the "hard anodization" condition. With a combined oxalic acid anodization followed by phosphoric acid anodization at 185 V, a pore-to-pore distance over 400 nm can be reached as shown in FIG. **3**.

[0012] In addition to large pore distance, another direction in the synthesis of AAO films is to go beyond the 2D hexagonal pore arrays toward 3D periodically perforated nanostructure network. A cyclic anodization process has been developed where an oscillatory current signal is applied to create AAO with pore diameter modulated by the applied current. The pore segments with larger diameter can be etched through to prepare periodically perforated nanopores. Another approach is to apply combined sequential mild anodization and hard anodization with pulsed anodization potentials to produce a lamellar typed 3D structure.

[0013] While there has been progress using AAO membranes for a variety of nanotech applications, an MCP detector has not been achieved using AAO membranes and conventional methods of creating AAO pore arrays have not been successful. Further, CVD based deposition processes generally lack thickness control, which may easily plug pores less than 200 nm in diameter, and therefore is generally not suitable for nanoscale fabrication. In particular, there is a substantial need for MCP detectors with micro-channel plates of much smaller intrinsic channel diameter (less than 1 micrometer), and micro-fabricated pores between approximately 1-25 micrometers and having a much faster response detection time of less than about 100 psec.

SUMMARY

[0014] The present invention includes an MCP detector designed for radiation detection and signal amplification applications fabricated from an anodized aluminum oxide (AAO) membrane containing a range of nanopores with about 10 nm to 500 nm pore diameters and then coated by an atomic layer deposition (ALD) process. The AAO membranes also can be prepared to have substantially uniform nanopores for each of the membranes with the values ranging over the above recited 10-500 nm pore diameters. Additional surface patterning techniques such as focused ion beam (FIB), lithography, and laser writer can be used to pattern the Al surface deposited on the AAO, to add features from intrinsic 10 nm to patterned 25 micrometers.

[0015] This MCP detector is fabricated based on AAO/ALD for micro-channel plates with much smaller intrinsic channel diameter (≦1 micrometer), micro-fabricated pores of about 10-500 nm, leading to MCP detector channels of about 1-25 micrometers in diameter and faster detector response time (less than 100 psec). Large-area AAO membranes and/or use of AAO imbedded in an Al frame in a tile format can be used to construct large-area MCP devices. The nanopores in AAO are generated with either hard anodization (200 nm to 1 micron pore-to-pore distance) or mild anodization (20-200 nm pore-to-pore distance).

[0016] AAO can be fabricated by combining surface patterning techniques such as focused ion beam (FIB), photo- and electron beam lithography (e-beam), laser writer, and nanoimprint with anodization to fabricate the precise pattern designed for the specific MCP applications.

[0017] The above aspects and features, objects and advantages of the present invention will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings described below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] FIG. **1** shows a single AAO pore;

[0019] FIG. **2** shows an atomic force microscope image of a 500×500 nm scan of an Al surface with highly ordered indents showing a pore to pore distance of about 110 nm;

[0020] FIG. **3** shows an atomic force microscope image of a 2×2 micrometer scan of an Al surface showing nearly ordered indents with a pore to pore distance of about 400 nm;

[0021] FIG. **4** shows a hard anodized structure in a 5×5 micrometer atomic force microscope image with a pore to pore distance of about 330 nm and a pore diameter of about 150 nm;

[0022] FIG. **5** shows a mild anodized structured in a 1×1 micrometer atomic force microscope image with a pore to pore distance of about 110 nm and a pore diameter of about 50 nm;

[0023] FIG. **6** shows a 10×10 micrometer atomic force microscope image showing an AAO pattern generated by use of a focused ion beam technique followed by anodization to form a structure with about 500 nm pore to pore distances;

[0024] FIG. **7** shows a 5×5 micrometer atomic force image magnified from FIG. **6** and the sample is AAO over an Al substrate;

[0025] FIG. **8** shows an SEM image with 15 micrometer diameter pores for an AAO structure for constructing an MCP detector, and the pores were formed by laser writter patterning followed by a chemical etch;

[0026] FIG. **9** shows an SEM image of an AAO pattern magnified from FIG. **8** and shows small intrinsic nanopores (about 30 nm pore diameter) that facilitated chemical etching to form the large 15 micrometer pores shown herein;

[0027] FIG. **10** shows a flat Al surface disposed on top and a textured Al surface with a bias angle θ on bottom;

[0028] FIG. **11**A shows a typical Al—Al_2O_3 sharp interface and FIG. **11**B shows a compositionally graded Al-alumina interface;

[0029] FIG. **12** is a schematic of a micro-channel plate constructed in accord with the invention;

[0030] FIG. **13**A-**13**D show the sequence in processing an AAO membrane by etching to prepare open AAO channels with a funnel-shaped entrance; and